A JOINT PROJECT FOR THE INVESTIGATION OF THE UTILIZATION OF THE SEL 840 MP FACILITIES IN CONNECTION WITH BIOMEDICAL RESEARCH

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CHAPTER I. INTRODUCTION

With the development of modern high-speed, large-capacity computers, increasingly more complex experiments are now being conducted in biomedical research. New experimental procedures and techniques are being developed as computers take over more of the experiment control functions. With the computer closing the loop between the experimenter and the experiment, the problem of efficient operations becomes more acute. Higher speeds and larger capacities do not by themselves lead to improved experimental performance; it is essential that the requirements of the research be matched by the computer equipment and techniques to be utilized. A fundamental study of the multidisciplinary aspects is required for effective computer applications to biomedical research.

This report presents one such study and its application. It is based on the computer support activities of the SEL facilities in the Biotechnology Division*, for ongoing research in the Life Sciences Division*. Following a section on the background for this project, a theoretical study of some aspects of biomedical research is presented and a multilevel computer system is designed for interactive experimentation. The discussion is general in scope, and is followed by a section on its application to an experiment in the Human Performance Branch*.

CHAPTER II. BACKGROUND

2.1 Ongoing Utilization. The project commenced in June, 1970, with a survey of the SEL facilities and the experiments utilizing them. The equipment considered for this project included:

1) the SEL 840 MP computer;
2) Calcomp XY (incremental) plotter;
3) Varian STATOS V (electrostatic) plotter;
4) Peripheral equipment such as paper and magnetic tape units, card reader, line printer, etc.;
5) Other equipment, such as the SEL 816 CRT - Light-pen unit, Evans and Sutherland Dynamic Display System (1971).

The laboratories then utilizing these facilities included:

1) Man Machine Integration Branch, Vision Laboratory;
2) Environment Control Branch, Environmental Laboratory;
3) Biomedical Research Branch, Thermoregulation and Cardiovascular Research Laboratories.

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* at NASA-Ames Research Center, Moffett Field, California.

2.2 SEL 840 MP Operating Modes. Access to the timeshared SEL 840 MP computer can be in either "Foreground" or "Background" modes. The Foreground mode consists of the direct inputs to the computer (of data from the laboratories). A system of priorities is incorporated into the SEL 840 Operating System software and teletype links are utilized by the laboratories for input commands. The Background mode consists of any external inputs to the SEL computer from its peripherals. In operation, the Foreground mode is dominant; Background mode processing can be interrupted to accommodate Foreground processing automatically by internal circuitry.*

2.3 Laboratory Connections. The laboratories have highly automated instrumentation such as the Vidar system in the Thermoregulation Laboratory. Some laboratories utilize a small on-site computer, such as the Man Machine Integration Branch PDP-8. Direct lines connect each laboratory to the SEL facility, where incoming data undergoes signal conditioning before computer input can occur. In addition, a teletype link is provided between the SEL facilities and the laboratories for signaling between the experimenter and the computer. The general purpose computer facilities of the Computation Division (Building 233) are also utilized for detailed off-line analyses; a new SEL 840 - IBM 360 intertie for direct data transfer was being considered. (At this stage, this study was initiated as "A Joint Project for the Investigation of the Utilization of the SEL 840 MP Facilities in Connection with Biomedical Research".)

2.4 The Human Information Processing Laboratory. In order to develop an extensive computer support system for applications to biomedical research, one particular laboratory was selected for especial study. This was the Human Information Processing Laboratory in the Human Performance Branch. Psychophysiological experiments were being conducted here by Dr. L. J. Leifer, in research on human decision making. The laboratory consisted of an isolation booth for subjects, and highly automated instrumentation for Stimulus-Response measurements of biopotentials, such as EEG, EMG, EOG, and evoked potentials. A LINC-8 computer was utilized on-site as the main processor, and special devices, such as the Computer of Averaged Transients (CAT), were available. Data acquisition, display and recording were performed by an Ampex DAS 100 system consisting of integral units for 12 channel signal conditioning and recording, and 4 channel oscilloscopic display.

Experiments were being conducted before our project started, and increased computer support was deemed necessary. This particular laboratory was selected for our study because of the complexity of the experiments planned, for which the system to be designed would find a direct application. In addition, the system could itself be flexibly designed so as to allow for improvements to be made as it developed, especially in the area of display equipment and techniques. Finally, the experiment provided an opportunity to develop and utilize new interactive procedures, so that the system designed could possibly find applications in other areas of biomedical research.

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*The SEL Realtime Monitor reference manual (6) defines the modes in the glossary (pg. A-1) as: Foreground Program: A program which is activated by a priority interrupt. The program may be resident or may be in load module form in secondary storage. Background Program: A program whose execution is directed by a Job Control statement rather than an interrupt.

2.5 The STATOS V Electrostatic Plotter. The STATOS V electrostatic plotter in the SEL facility was an item of interest for this project. The basic principles of operation are outlined with the aid of Figure 1.A "comb" structure of 1024 "pens" (10 inch length) is fixed above the surface of specially treated paper. Writing is accomplished by connecting a high voltage to the required pens, which transfers a charge to corresponding points on the surface of the paper as it is moved past the comb by the paper drive mechanism. When the paper moves through the toner bath, ink particles are attracted to the charged areas, and are seen as black marks on the white paper. By actuating more than one pen in an area, a cluster of marks is obtained, which provides some "shades of grey" capability for this display device. All the pens are directly addressable, and the number, position, and scaling (or channels) can be software controlled. This plotter can generate multichannel displays much faster than conventional plotters using servo-driven-pen mechanisms.

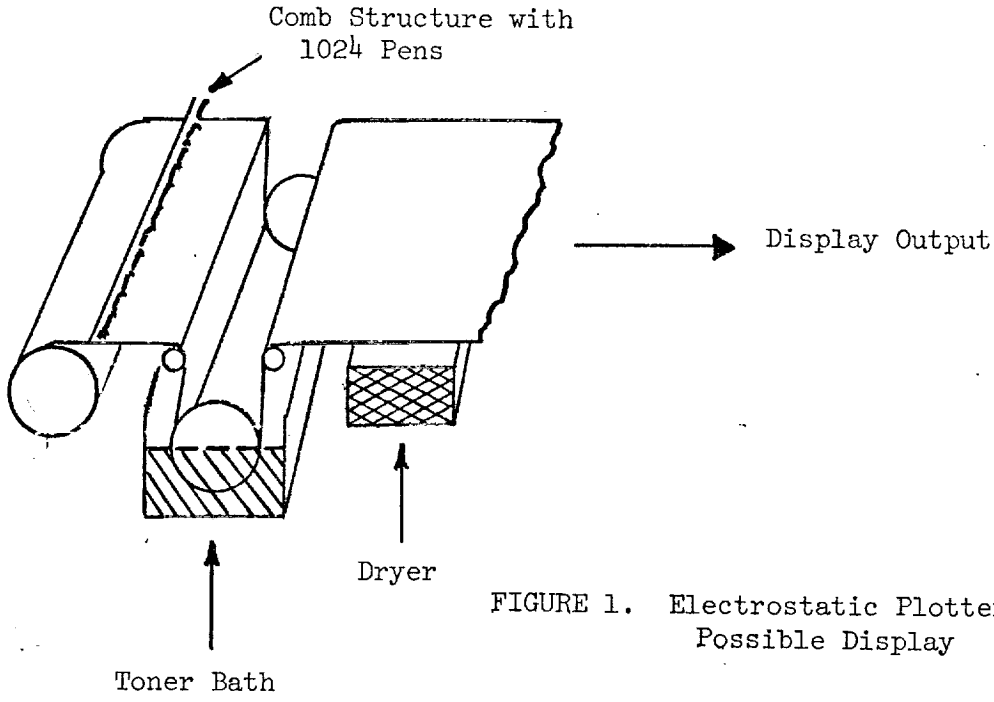
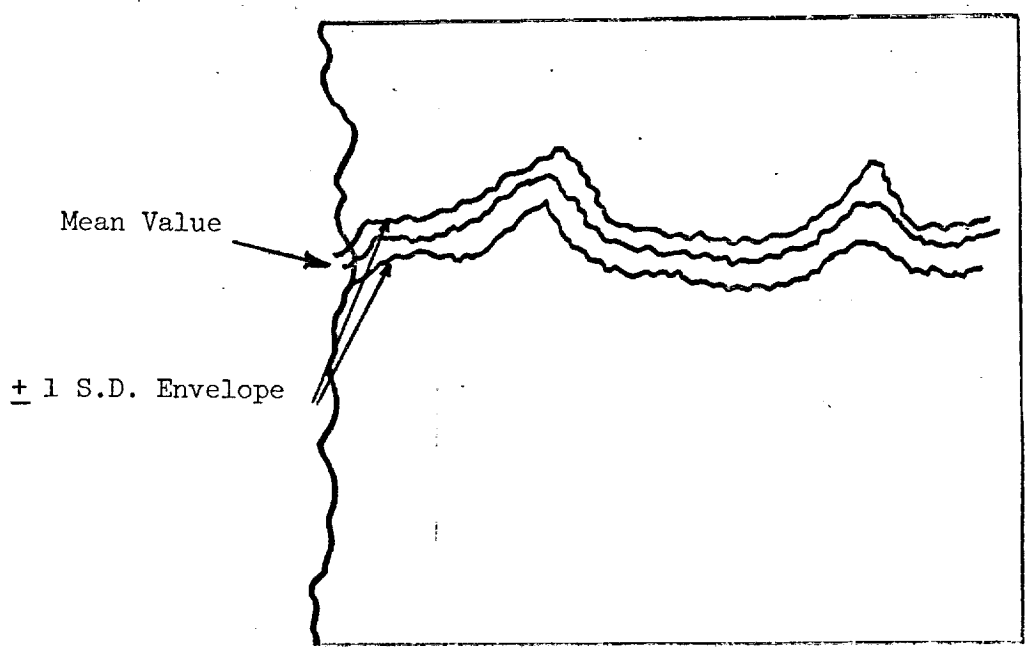


FIGURE 1. Electrostatic Plotter
Possible Display



CHAPTER III. THEORETICAL DEVELOPMENT

3.1 Research Procedure. The progress of experimental research follows an iterative process consisting of a succession of stages. An hypothesis is made, an experiment is performed, and the results are analyzed to modify the initial hypothesis, thus completing one such stage. Research in the life sciences involves the study of a large number of interacting variables, and hence the experiment phase is broken down into several "runs" concerning one variable at a time. Each run consists of many repeated "trials" of parameter measurements. A run may consist of a hundred repeated trials, the data from which is statistically analyzed to obtain a "typical" response for the measurements. Different parameter combinations are observed in different runs of the experiment; this information is then studied in the analysis phase of the research.

3.2 Experimental Data. In complex experiments, data are available at different "levels" as follows. These have different characteristics and data processing requirements; and the information obtained is utilized for different purposes. Initially, the measurements of raw data are observed primarily for the nature and accuracy of the response itself. Incoming signals are filtered for an acceptable range and values outside this range of parameters are discarded. At the end of a run, the many repeated measurements are analyzed with preliminary statistical tests to obtain typical patterns and distributions. The combination of parameters is changed, other trials are conducted, providing data for different runs. When several runs are completed, the data is studied with further statistical analyses to determine correlations among the variables isolated in the different runs. Finally, the information collected at the end of the experiment is analyzed in detail so as to evaluate the initial hypothesis, thus completing one stage of experimental research.

3.3 Interactive Experimentation. In many experiments involving several interconnected variables, the outcomes vary with the combination of parameters selected. For example, the inclusion of or exclusion of feedback paths for a variable provides two different outcomes. When these effects are not clear in advance, it becomes very desirable to allow for the experimentor to interact with the experiment. The results of utilizing a certain combination of parameters are noted as they occur, and the combination can then be altered for best results before any erroneous or undesirable effects become deeply embedded in the experimental procedure or data collected. Without this provision, the experimentor would have to complete an entire stage, making some unnecessary measurements and analyses before the best combination of parameters is obtained. This complex and time consuming procedure may not allow for the examination of more than one variable at a time, and some interactions may not be observed at all. From the discussion in 3.2 above, the best point for the inclusion of capabilities of interaction is at the end of a run, when data from a combination of parameters is obtained. The flow of information is modeled in Figure 2.

3.4 Man-Machine Communications. Communications in Man-Machine systems consists of signals from man to machine via controls (which are relatively standardized), while for the return path, machines communicate to man via displays, where there is much room for variation. Apart from the obvious choice of channel itself (i.e., visual, audio), the nature of the display in terms of form and complexity can be varied (for example, graphs, mathematical symbols, etc.). The human brain has the capacity for extensive pattern recognition functions which can be used to advantage for input data interpretation. Thus, for instance, when some accuracy can be traded off for a large increase in speed, data input to man should be in the form of a graphical display instead of detailed printouts of actual numerical values. Also, information on trends and distributions is more readily received from graphical displays, which are thus useful in interactive experimentation. The system designed should be flexible to allow inclusion of other human factors [1] that may prove to be useful.

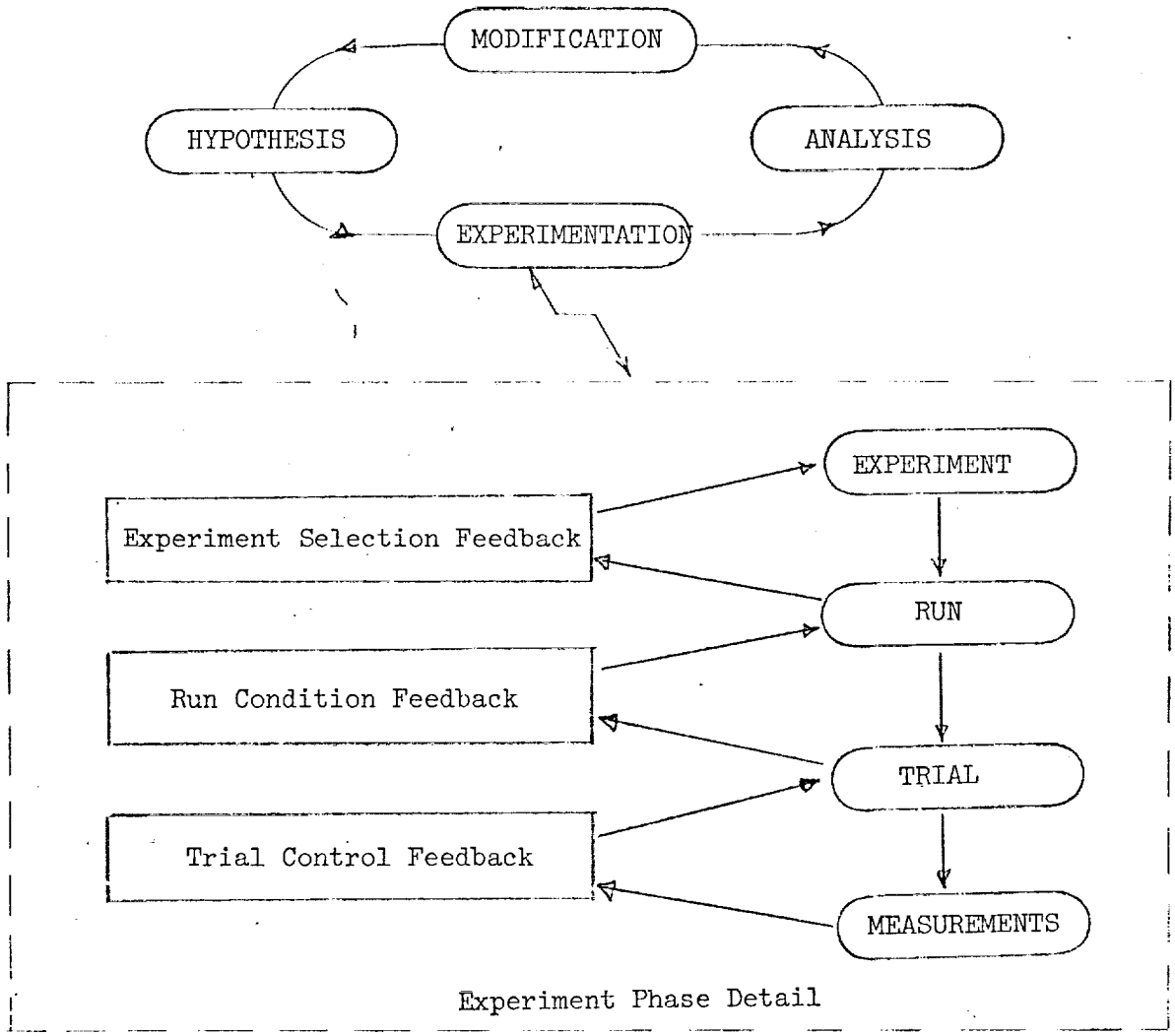


FIGURE 2. Information Flow Within a Stage of Experimental Research

CHAPTER IV. SYSTEM DESIGN

4.1 Requirements. The system designed must meet the experimental requirements in the areas of experiment control, and data acquisition, analysis and display. Experiment control functions differ with each experiment, and include stimulus selection and presentation, response acquisition and display, and the generation of control signals to the instrumentation, recorders, etc. The task of data processing begins with the acquisition of raw data measurements. The different characteristics seen in 3.2 can be grouped into three levels, with the automated instrumentation included as a sublevel in the first level. At the laboratory, simple control signals provide the stimulus, and a direct oscilloscopic display is sufficient for the initial range setting and calibration of instruments. At the first level, the measurements are digitized to obtain trials data, continuously and in real-time; the memory and processing requirements are not large, since experiment control programs and response data can be stored on magnetic tapes. Processing includes Analog to Digital conversion, data checking, tabulation, and some calculation such as averaging. A digitized display of the averaged response is provided on a CRT.

Data processing at the second level is required at the end of each run. This includes formating, processing a large data base with elementary statistical tests, and providing high speed graphic displays. A medium sized computer is required for short durations periodically during the course of the experiments. Third level data processing requirements occur at the end of a series of runs; detailed statistical analyses are performed to determine correlations among the trial variables. Also, at the end of the experiment phase, the data is analyzed to evaluate the initial hypothesis and make modifications, for further research. A large capacity, general purpose computer is required; the utilization is off-line, but a high speed machine is required to perform the detailed anayses and provide printouts.

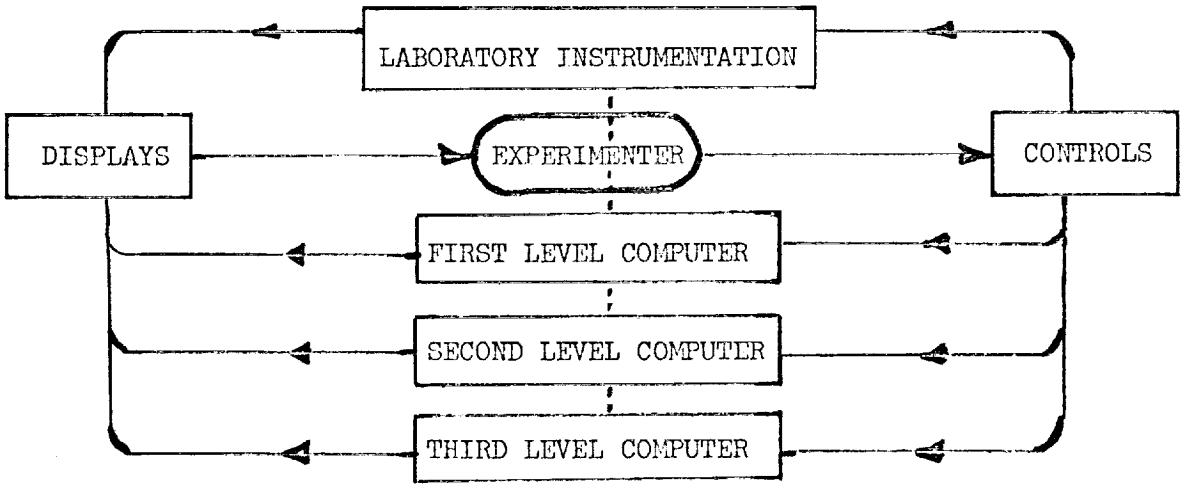
4.2 Equipment Selection. The data processing tasks for the three levels could be performed by one central computer; but this would hamper the progress of the experiment, which must then be interrupted at each level for the data processing to occur. Three similar machines for the three levels would be an inefficient allocation, since each level has conflicting requirements of timing, and different requirements for computer capacity and speed. Thus the system designed should utilize three different machines in an optimal configuration to meet the total requirements, as follows.

The first level requirements are met by a small (8 K core, 16 bit word) computer, dedicated to a particular experiment. A CRT display of digitized data is sufficient, and software is in machine language since the programs for a particular experiment are not general purpose routines. For the second level, a medium sized (32K core, 32 bit word) computer is timeshared among other first level computers in the research center. Displays include high-speed graphic hardcopy devices, such as incremental as well as stripchart types. Software is largely in assembly language, with some possibilities for using simple general purpose routines in FORTRAN, etc. The third level requirements are met with a large (100K core, 64 bit word) high-speed, general purpose computer, with extensive Fortran routines and assembly language programs possible in its library. Displays are required of detailed calculations, largely in the form of hard-copy graphs and printouts for permanent records. Table 1 summarizes these criteria and equipment characteristics.

Computation		Requirements For			Level of		Computer Application	
No.	Phase	Capacity	Timing	Display	Experimental Correspondence	Primary Utilization	Hardware	Software
1	Acquisition	Low	Real Time	Direct	Trial	Data Verification	Dedicated (8K)	Symbolic
2	Formating	Moderate	Short Intervals	Computed	Run	Decision Making Aid	Timeshared (32K)	Symbolic FORTRAN
3	Analysis	High	Off Line	Detailed Analytical	Run, Experiment	Theoretical Analyses	Batch Processed (100K)	FORTRAN Machine Language

TABLE 1. Summary of System Design Criteria

Figure 3. Proposed Multilevel Configuration.



Note: . . . . . indicates data paths

——————— indicates experimenter interaction paths

4.3 Proposed Multilevel System. Figure 3 shows a model of the proposed multilevel system for interactive experimentation. In operation, the experimenter first calibrates the equipment in the laboratory, and begins repeated trials. The first level computer receives the incoming data continuously; the trials data are checked, digitized, stored, and displayed on the digital CRT. At the end of a run, data is transmitted to the second level computer, which performs tasks of formating, elementary statistical testing, and display on high-speed graphical equipment. The information displayed here can be the basis for a decision to rerun portions of the experiment, make changes in the parameter combinations, etc., in an interactive experiment. When data from several runs of an experiment is obtained, it is analyzed in detail off-line, at the third level computer, to determine correlations. The experimenter now has another point for interaction; additional runs may be conducted to study some parameters as suggested by the data obtained. Finally, theoretical analyses for the analysis phase of the research can be performed, utilizing the routines available at the third level computer software library.

CHAPTER V. APPLICATION TO HUMAN FACTORS RESEARCH

5.1. System. Computer support for experiments conducted by Dr. L. J. Leifer in the Human Information Processing Laboratory, is provided by a system as described in 3.4 above. Automated instrumentation (Ampex DAS 100) and an on-site computer (LINC-8) are in use at the laboratory, to provide first level data processing capabilities. The SEL facilities are utilized for second level data processing, and the IBM 360 in the Computation Center (Bldg. 233) provides third level processing facilities. These three computers and other equipment are utilized in the configuration shown in Fig. 4.

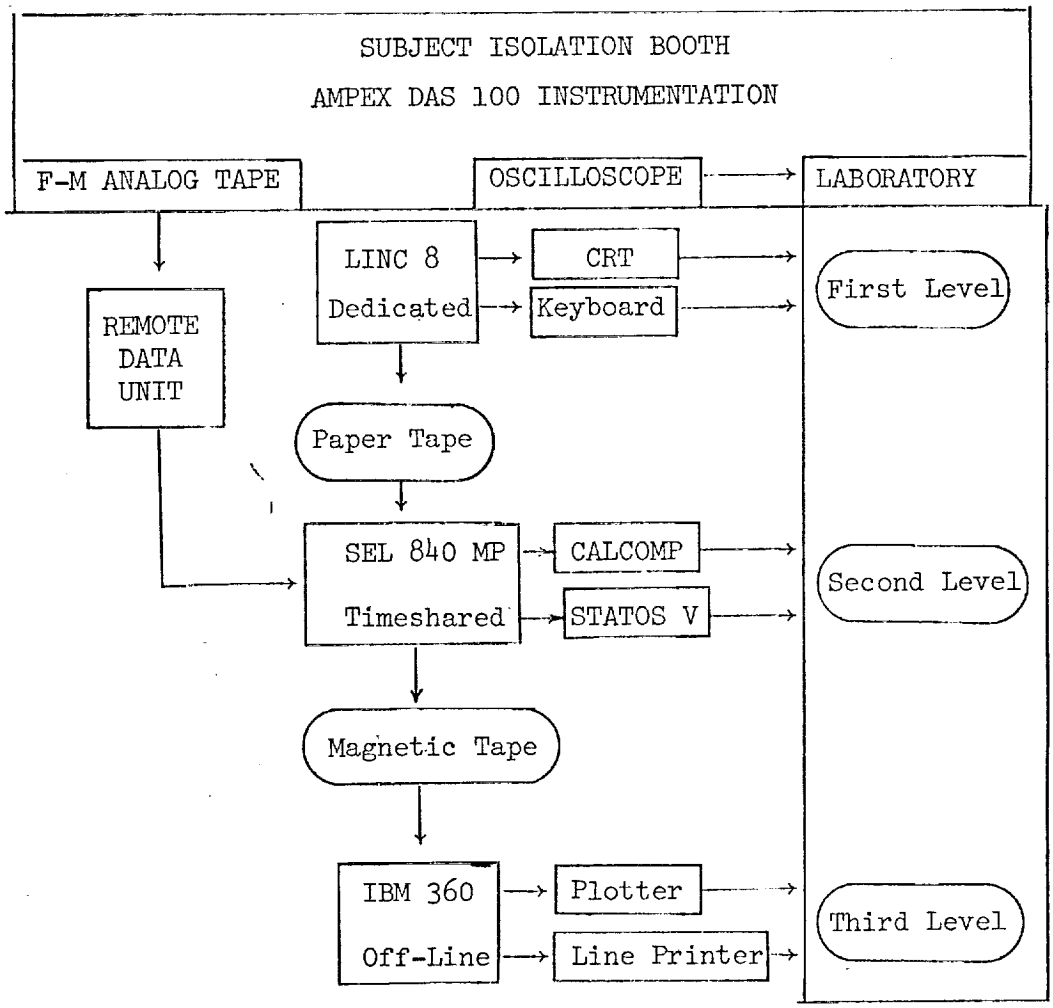


Fig. 4. Computer System for Human Information Processing Experiment

5.2. Experiment Description. In the current probability learning studies, a typical experiment run is composed of 500 trials. Each trial is structured as follows:

1. A "?" is displayed to the subject indicating that he should predict which of four possible visual stimulus characters he expects to see next.

2. The subject enters his prediction by pressing one of four buttons within 1-1/2 seconds of the "?" display onset. A prediction entered at any other time is scored as a mistrial.

3. A lower-case version of the predicted stimulus character immediately replaces the "?" and is displayed for 2 seconds.

4. At the end of this 2-second expectancy interval (ISI) an upper-case version of the stimulus character, actually next in the computer controlled sequence, is displayed for 0.2 seconds.

5. At the end of this character display the screen is blanked (leaving only the oscilloscope grid as an aid to visual fixation).

6. A "randomized" inter-trial interval (ITI) of 3 to 6 seconds separates successive trials.

The trial sequence, and its corresponding average evoked potential (AEP), are presented in Fig. 5. The AEP measures currently used are also shown; the baseline formed by the mean voltage level for a one-second period preceding the trial. During the expectancy interval the maximum negative excursion and the integrated negativity are taken as measures of contingent negative variation (CNV) [3]. Following the stimulus character the maximum positive excursion and the integrated positivity are taken as measures of the P300 [4]. The CNV and P300 have been associated with expectancy, attention, motivation, and information recognition. These hypotheses are tested on subjects whose task is to learn Markov probability structures for the four visual stimulus characters.

5.3. Processing Configuration. The experiment control system (Fig. 5) is designed around a small computer, the LINC-8, dedicated to providing event timing, stimulus display, and behavior scoring, and "bookkeeping"; these tasks saturating its real time capabilities. Two "bookkeeping" functions during the experiment are as follows: First, trial identification markers are transmitted to the analogue tape recorder for each trial, consisting of pulse amplitude modulated characters in a 24 bit code. One marker preceeds each trial and contains the trial number and subject identifier. A second marker follows the trial and contains the subject's prediction, reaction time, and actual stimulus character. These three variables and an alpha frequency-band estimate of the subject's attentiveness are considered to be the measures of behavior and are stored digitally on the system disk. The digital record is subsequently used to identify trials in which specific behavior patterns have occurred. The number of a selected trial goes into an acceptance table for off-line selective A/D conversion.

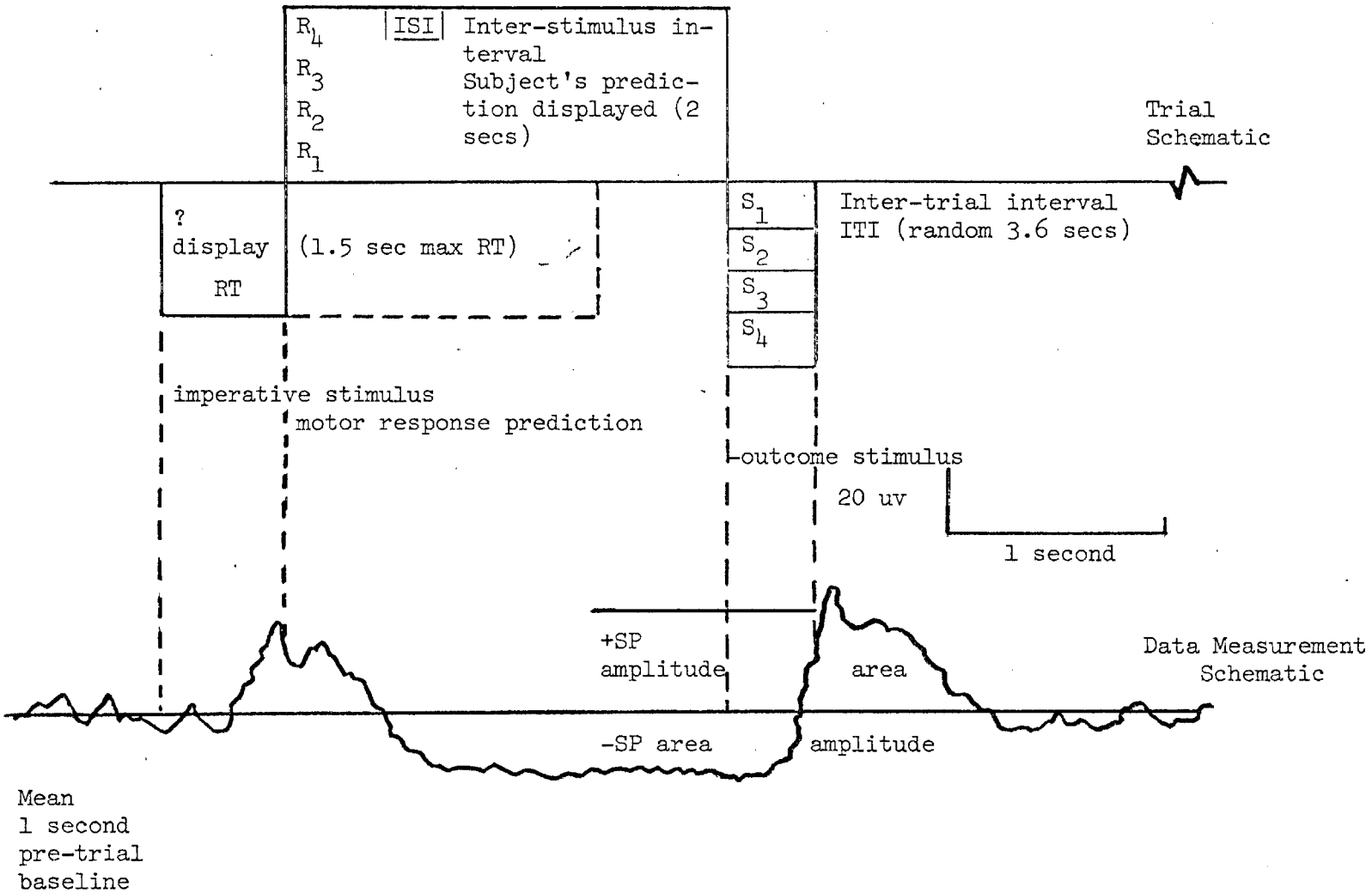


FIGURE 5 - Experimental Trial and Data Measurement Schematic

Data processing and analysis are assigned to three different processors (Fig. 4). The LINC-8 is the original processor and most of the tasks were first executed on that machine. Subsequent availability of larger machines has lead to a transfer and expansion of these tasks, yet no one computer is appropriately assigned to perform all tasks. The most desirable arrangement has been a complementary mix of these systems. Table 2 briefly identifies the current task allocation. This overall system has not been optimized, but each step in the development has reduced the time delays between conceptualization, implementation, and review of experimental results. The approach has proved to be satisfactory and its full potential in a wide variety of psychophysiological research is being investigated and developed.

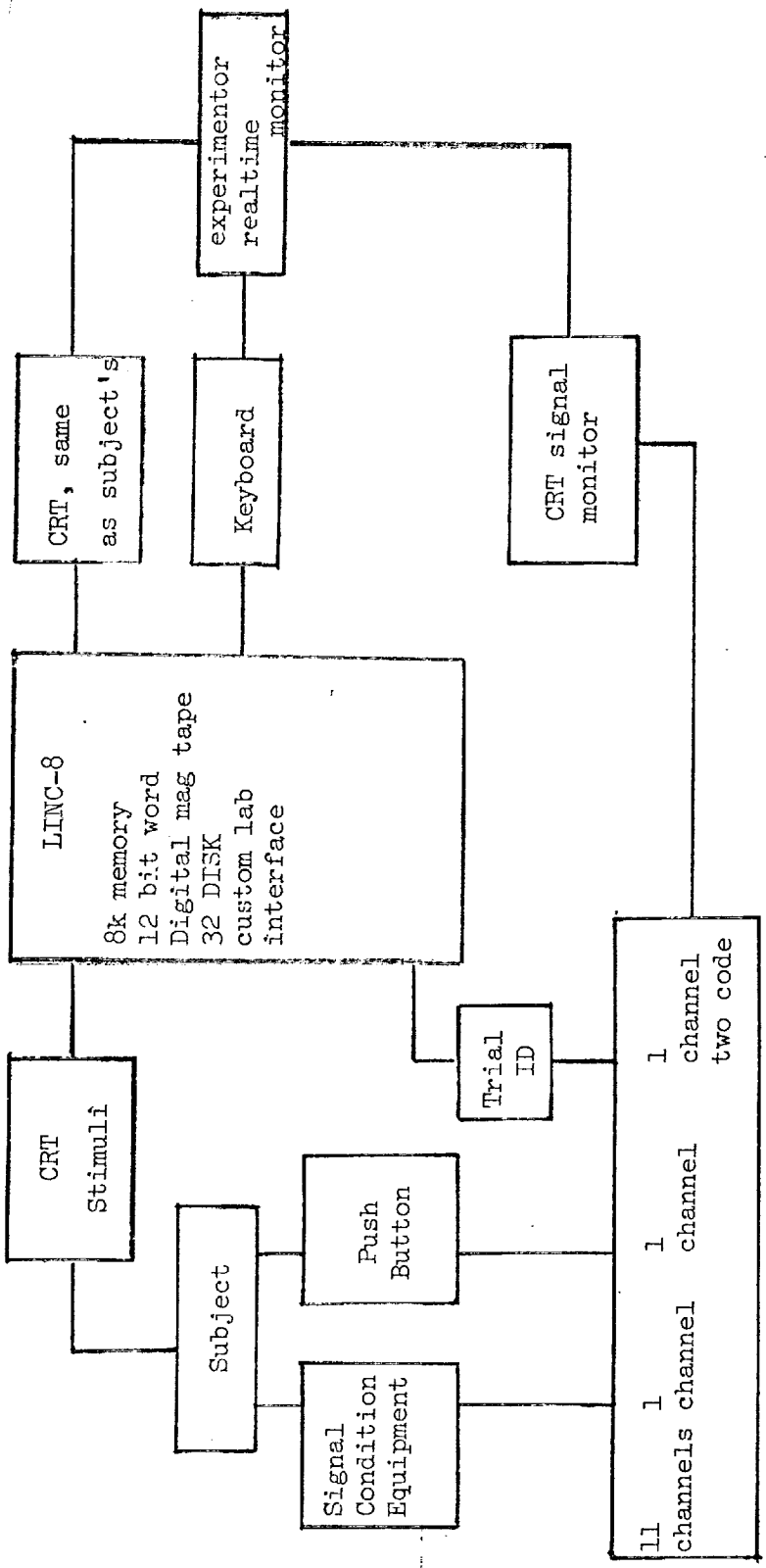


FIGURE 6 - Experiment Control

LINC-8

(12 bit, 8k, DEC-Tape, 32k Disk)

1. A/D Conversion
   a. 1-4 channels
   b. 1K words sets
   c. off-line only
   d. Display monitor of A/D

2. Behavior Analysis
   a. Simple pattern selector
   b. Discrete measures only
   c. Trial #tables
   d. Very low-speed

3. Displays
   a. Highly interactive data display 1-9 channels
   b. Data plot

4. Data Processing
   a. 1-4 channel sign averaging
   b. Digital filter

SEL 840MP

(24 bit, 32k, 2500 disks, IBM Tape

1. A/D Conversion
   a. 1-12 channels
   b. 12K words sets
   c. On and off-line

2. Displays
   a. STATOS IV ELECTROSTATIC
   b. Interactive display capability
   c. Incremental plot capability

3. Data Processing
   a. 1-12 channel averaging with confidence estimation
   b. IBM compatible tape formats
   c. Data Transformations
   d. Digital filter
   e. Mean, SD, Integral Measures

IBM 360-67

(64 bit, 100k, disks IBM Tape)

1. Behavior analysis
   a. Complex behavior pattern analysis
   b. Discrete and continuous variables
   c. Trial #tables
   d. High speed

2. Data Processing
   a. Discriminant analysis
   b. Spectral analysis
   c. Analysis of variance
   d. Factor analysis

TABLE 2. Data Processing Task Assignment

CHAPTER VI. SEL FACILITIES UTILIZATION AND RESULTS

6.1. The decision to utilize the SEL facilities in connection with the research in the Human Information Processing Laboratory was made in June, 1970, after a survey of the ongoing research. The interconnection requirements were studied, and cables linking the laboratory to the SEL facilities were installed in July. It was decided to specify a flexible interconnection unit which could be moved to another laboratory if required. Thus, the Remote Data Unit was specified, and it was built by the Instrumentation Division in December. Simple statistical tests such as averaging and confidence estimation, and display devices such as the STATOS V plotter were studied for application to Dr. Leifer's experiments; a trial method was developed and reported in November, 1970. During 1971, some aspects of the research method were studied for the design of an interactive computer system, and two other reports were published in September, 1971, on system design, and displays. (These are listed in PUBLICATIONS, p. 21 of this report). Partial implementation of the system then continued beyond the SEL facility, utilizing the IBM 360 for statistical analysis. Experimental data from the laboratory LINC-8 (on paper tapes) were processed at the SEL facility, and the results reformatted (onto magnetic tapes) for further processing at the IBM 360 computer. Here the data (from the magnetic tapes) was analyzed using a BMD routine [5], providing a printout of linear correlation analysis, in January, 1972. (See pgs. 16, 17, and 23 for typical results).

6.2. Display Evaluation: Equipment. Displays were investigated further, and it was found that the STATOS V model in the SEL facility had some drawbacks for our application. It was designed to operate in a manner similar to a strip-chart, placing the burden of data coding, channel formatting, and timing on the (SEL 840) computer. Operating in the Background mode, only the writing circuits would be interrupted by the Foreground; the paper drive mechanism continued to advance the paper, thereby disrupting the scale on the longitudinal axis. (The plotter did have a discrete-step feature, but it required commands from the computer at special intervals; this would create yet another load on the SEL computer). Further, the high resolution pens caused displays of single events to appear as very fine dots, spaced apart (Fig. 7). To obtain a visible continuous plot, several adjacent pens must be activated in a cluster; this would again impose on the SEL computer. These factors together reduce the applicability of the STATOS V to the presentation of final display graphs, using pre-formatted data played back from magnetic tapes. Hence, other graphical display methods were investigated in March, 1972.

6.3. Display Evaluation: Techniques. At the University of Santa Clara, Department of Electrical Engineering and Computer Science, an IBM 1130 computer was used to model the SEL 840 function as the second level computer for the purpose of generating displays for interaction, on a Calcomp incremental plotter. Input data at the IBM 1130 was subjected to formatting, averaging and statistical testing; graphical displays were obtained on the incremental plotter. These graphs displayed the computed mean value with a $\pm$ 1 standard deviation envelope of the AEP. The actual values were listed in a printout initially, but they were not required; instead, the calculated value of the standard deviation at each time interval was printed under the main graph. At first simple lines on either side of the mean value graph displayed the envelope. A "high-low" plot with connecting line segments was tried and found to be more suitable for visual interpretation; the relative spread of data values at a point could be observed displayed without overshadowing the graph of the graph of the mean value.

	from trial #	to trial #	$\overline{P}$ wave	d$\overline{P}$ wave	$\overline{E}$ wave	d$\overline{E}$ wave	% A	d% A	% C	d% C
1	2	52	30		- 5		22	-3	18	-7
2	52	102	44	14	-18	-13	50	28	40	22
3	102	152	33	11	-17	1	42	-8	24	-16
4	152	202	33	0	-13	4	46	4	36	12
5	202	252	28	-5	- 8	5	46	0	30	-6
6	252	302	28	0	-15	-7	60	14	44	14
7	302	352	24	-4	- 9	6	52	-8	40	-4
8	352	402	29	5	-12	3	58	6	40	0
9	402	452	26	-3	- 5	7	54	-4	44	4
10	452	502								

$\overline{X}$ = -11.3 $\overline{X}$ = 3.22

SUBJECT L1Ø2-CZ

TRIAL TYPE Unselected

DATA & WHO 3/7/72: Leifer

TABLE 3 - Results: Data From SEL Computer

```
L1Ø2-CZ   EWAVE/TRIAL BLOCK

LINCOR

LINEAR CORRELATION

NO. OF DATA POINTS= 9

NO.      X      Y
+1      -5    1
+2      -18    2
+3      -17    3
+4      -13    4
+5      -8     5
+6      -15    6
+7      -9     7
+8      -12     8
+9      -5     9

SUM X=-Ø.1Ø2ØØØE+3          SUM X SØ=+Ø·1346ØØE+4
SUM Y=+Ø.45ØØØØE+2          SUM Y SØ=+Ø·285ØØØE+3
SUM XY=-Ø.478ØØØE+3

MEAN S= -Ø.113333E+2        MEAN Y= +Ø.5ØØØØØE+1
SIGYA X=+Ø.487339E+1        SIGMA Y=+Ø.273861E+1
R=+Ø.2997Ø7E+Ø
N=+9

REGRESSION EØ
Y=+Ø.168421E+Ø      X=+Ø.69Ø877E+1
S·E·=+Ø.261272E+1
```

TABLE 4 - Results: Printout From IBM 360 Computer

Values for the Coefficient of Variation were computed, but for display they had to be numerically inverted; low values in the denominator of the function caused the graph to exceed the scale unexpectedly, and these excursions had no experimental significance.

A new index proposed in our first paper was tried - the actual number of data measurements that occurred within the ± 1 Standard Deviation envelope. These values were displayed as a graph, under the main data plot. When this index graph was compared with four different runs, a variation was observed. The index was generally higher for a run of "Astute, Correct" trials than for "Unastute, correct", during the Inter Stimulus interval. The significance of this could not be determined before this project concluded; (the work was delayed by the need to transcribe data from LINC-8 paper tapes to IBM cards, via digital magnetic tape at the SEL and Computer Center facilities).

Fig. 8 shows the copies of these displays obtained in August, 1972, at the conclusion of this project.

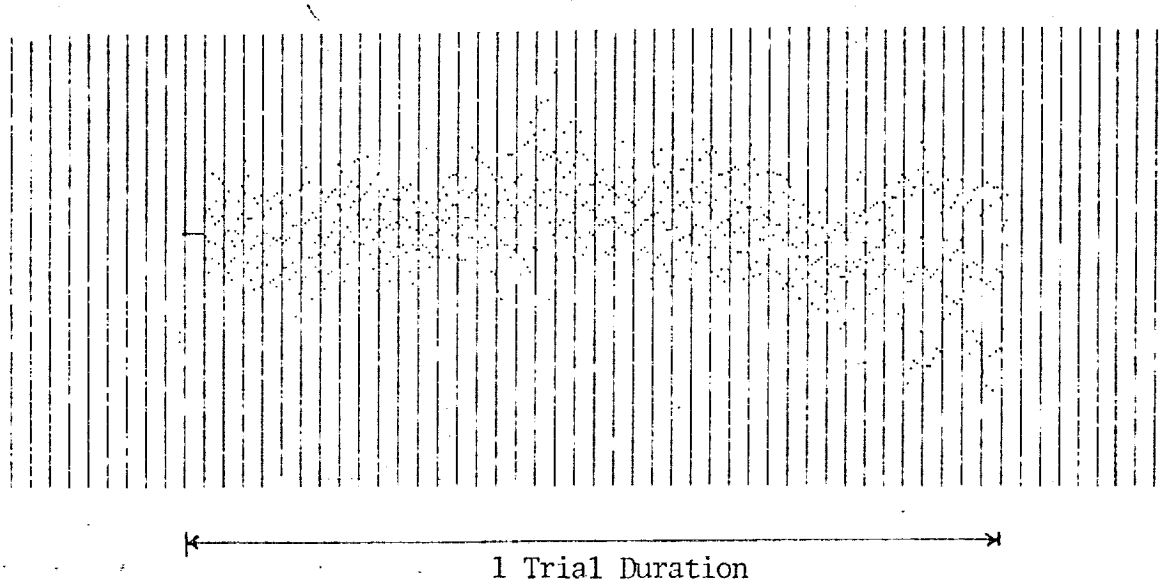


FIGURE 7 - STATOS V Display

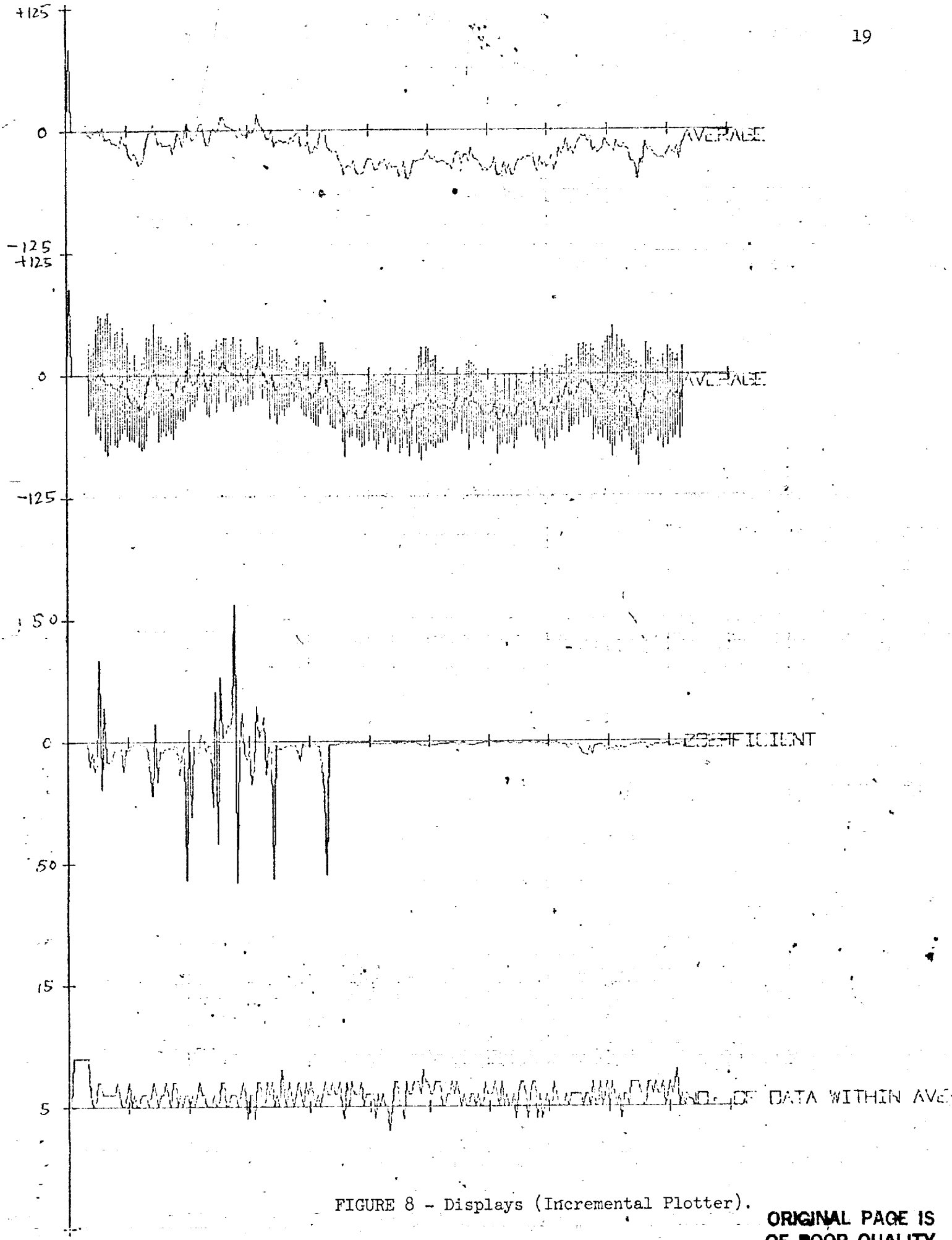


FIGURE 8 - Displays (Incremental Plotter).

CHAPTER VII. CONCLUSION

The characteristics of computer aided biomedical research have been examined in this report for the development of a multilevel computer system. It was shown that the inclusion of capabilities for the experimenter to interact with the experiment can lead to increased experimental performance; decisions on experiment control and parameter selection can be made while the experiment is in progress. The SEL facilities were investigated, and an application of the multilevel computer system incorporating the SEL facilities is described for an experiment in Human Factors research. Each step in the development of the system has reduced the time delays between conceptualization, implementation, and review of experimental results. The approach is general in scope, and should find applications to other experimental research. In addition to experimental research, applications for this procedure can also be found in continuous monitoring, such as chronic-patient monitoring. The systematic procedures described will help prevent haphazard computer system growth, and lead to more efficient operations.

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PUBLICATIONS

Based on the research activities for this project, three papers have been published, as follows:

TITLE AND VENUE:

(1) "Confidence Estimation for Evoked Biopotentials Measurements" Fourth Asilomar Conference on Circuits and Systems, November 18-20, 1970, Pacific Grove, California;

(2) "System Design Considerations for a Computer Application in Electrophysiological Research" and

(3) "Displays for an Interactive Experiment in Electrophysiological Research".

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APPENDIX

SUPPLEMENTARY DATA PROCESSING AND DISPLAY AT THE UNIVERSITY OF SANTA CLARA

A.1. Introduction

This describes the elementary statistical testing and display of EEG data from Dr. Leifer's experiments. In the laboratory, eleven channels of EEG are continuously monitored while stimulus/response experiments are performed. Finite length segments from the EEG, with a marker to indicate the presentation of stimulus, are digitized by the LINC-8 computer. This data is checked for accuracy (conforming to timing formats) and accepted trials are grouped into 4 categories based on "astute" and "correct" combinations. Each set of trials data is called a block and there may be 20-50 or more blocks in each group. The trial period T is divided into 256 intervals (t_i) corresponding to the sampling intervals. Thus, the data is recorded as an amplitude vs. time series. However, for convenience in paper printouts, the series is stored in a matrix form, with 8 columns and 32 rows. An additional row and column provide index numbering of the data matrix (for ease in locating data for a particular time interval). Heading each data matrix is a line of identifying information; the printout of one block is shown in Fig. A-1.

A.2. Input Data Conversion

Before any calculations can be performed (at the University of Santa Clara, IBM 1130 computer), a conversion is necessary. In the Human Information Processing Laboratory at Ames/NASA Research Center, data are recorded in octo-decimal form in a code scaled to include negative numbers as follows. Each octal digit can only represent numbers from 0 through 7, making the highest value possible in four digits equal to 7777 (octal). However, the data measurements can have positive and negative excursions of values not generally exceeding 3000 (octal). Hence, negative numbers are represented as their "8's complement", the sign is dropped, and the measurements with negative values will be recorded as within 7777 - 4000 (in order of increasing negativity). Thus, at the IBM 1130 computer, incoming data is first converted into true decimal (with sign and magnitude) form, and then subjected to the elementary statistical tests described next.

A.3. Tests

At each of the 256 sample times (t_i) in a block of data, the amplitude (a_i) of (that one channel) EEG data is obtained from the data matrix described earlier. Let N be the number of blocks for one group (N is typically 20 - 50 blocks). Then the following calculations are made:

(a) Average

$$\bar{a}_1]_N = \frac{(a_i)_1 + (a_i)_2 + \ldots\ldots + (a_i)_N}{N} = \frac{1}{N} \sum_{n=1}^{N} (a_i)_n$$

(b) Standard Deviation

$$s_i = \frac{\sum_{i=1}^{N} (a_i - \bar{a}_i]_N}{N}$$

(c) Coefficient of Variation

$$c_i = \frac{a_i}{s_i}$$

(d) Number of data points within $\pm$ 1 Standard Deviation of average value.

$n_i = \sum_{N} k$ where k = number of a_i actually measured such that

$$(a_i - \bar{a}_i) \leq a_k \leq (a_i + \bar{a}_i)$$

Data Formats are shown in A.4 below and in conclusion, copies of graphical displays on the CALCOMP plotter are obtained.

A.4. Data Formats

The input consists of a lengthy record of N blocks of time-serial data, as shown on the next page. (Fig. A-1). In processing at Santa Clara, the headers are removed, data from the N matrices is converted to true decimal; and stored. Then the calculations are performed, and the results stored as matrices for Average, Standard Deviation, etc. These calculated values can be called out for display.

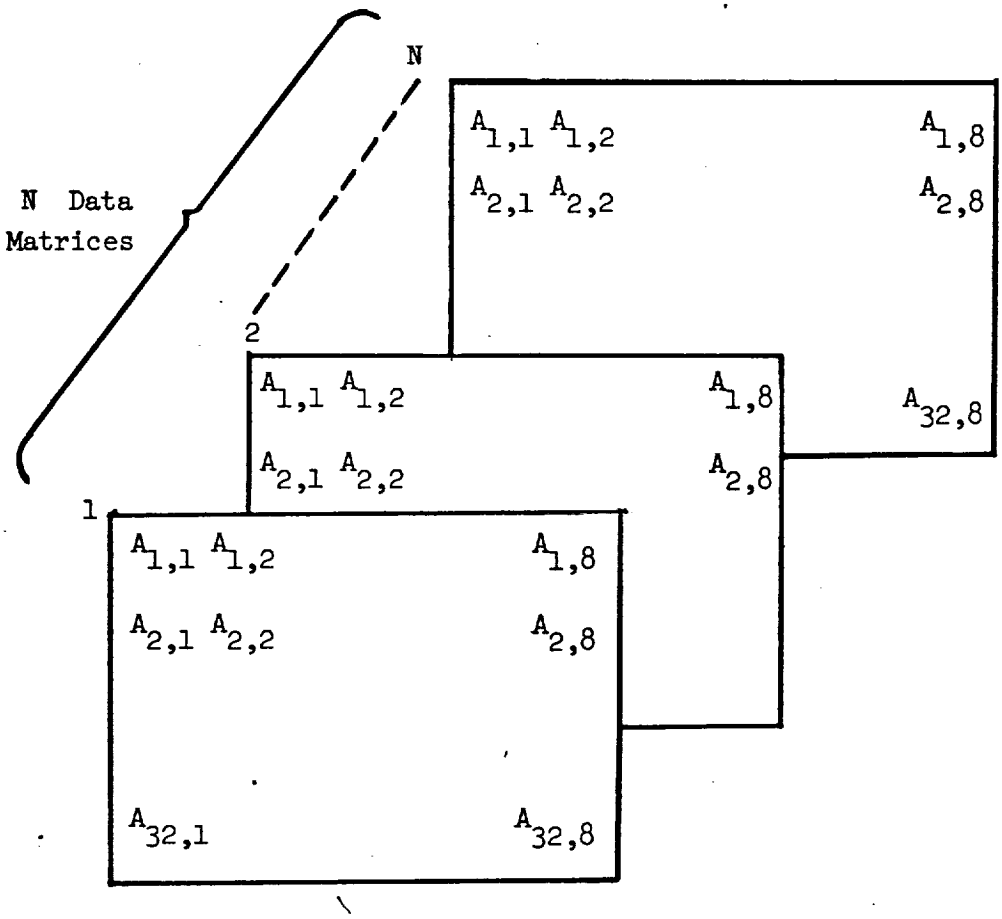
A.5. Displays

A copy of the typical display obtained on the Calcomp plotter is shown on page 20.

TAPE DUMP OF BLOCK 010

WORD	+0	+1	+2	+3	+4	+5	+6	+7
0000	0010	0000	0000	0000	0000	0000	0000	0000
0010	0023	0044	0074	0044	0115	0062	7761	0012
0020	7764	0027	0021	0047	0032	0035	0075	0075
0030	0121	0105	0056	0053	0075	0135	0174	0166
0040	0110	0050	0065	0111	0065	0025	0025	7772
0050	0002	7763	0011	7767	7767	7722	7771	0030
0060	0112	0052	0073	7765	0017	0050	0047	0013
0070	0047	0027	7764	0071	0115	0043	0034	0062
0100	0035	0025	0072	0071	7774	0015	0003	0015
0110	0016	0005	0054	0060	0015	0003	7774	0021
0120	0052	0003	0013	0001	0054	0065	0074	0062
0130	0042	0043	0014	7757	0043	0050	0041	0033
0140	0032	7760	7763	7763	0002	0033	7774	7753
0150	7756	7753	7752	7745	7772	7763	7742	7742
0160	0013	7775	7741	7774	7777	7736	7737	7755
0170	7752	0024	0021	0012	7764	0047	0035	0055
0200	0051	0055	0036	7763	0007	0032	0025	0002
0210	0222	0027	7752	7764	7776	0016	0034	7766
0220	7774	7777	7764	0003	0017	7777	7750	7723
0230	7730	7741	7725	7714	7676	7720	7735	7723
0240	7751	7706	7676	7711	7707	7714	7755	7757
0250	0026	0004	7753	0006	0052	0054	0062	7773
0260	7774	7755	7765	0051	0141	0046	7776	7741
0270	0002	0050	7776	0026	0014	0005	7775	0056
0300	0036	0027	0005	7776	7767	0040	0055	0104
0310	0105	0054	0022	0070	0035	0060	0044	0100
0320	0027	0013	0032	0032	0031	0103	0022	0057
0330	0053	0007	0033	0114	0053	0005	0031	0060
0340	0074	0102	0051	0036	7757	0017	7776	0046
0350	0051	0040	0050	0033	0075	0060	0023	0014
0360	0016	0045	7757	7741	0003	7777	0024	0027
0370	0044	0034	0100	0055	0046	0064	0050	7772

FIGURE A-1. Printout of a Typical Data Block (LINC-8)



Calculations on these N matrices provide data compression, resulting in the following blocks:

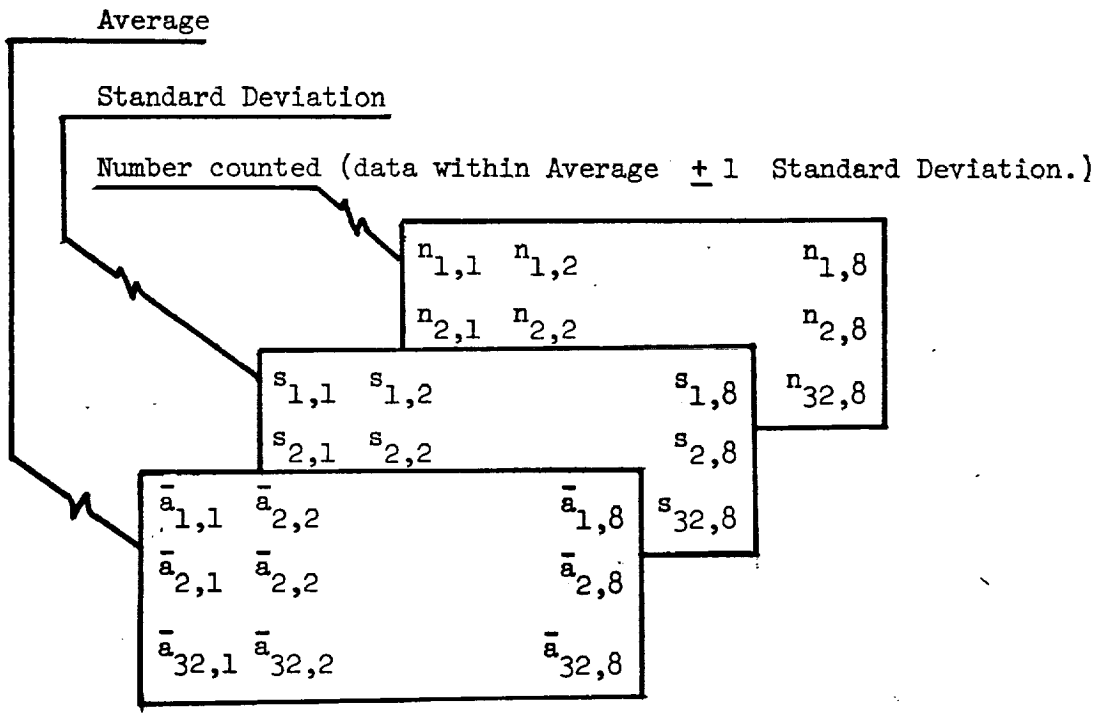


FIGURE A-2. Data Processing Summary

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